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Radon Mitigation Choices in the United States
A Comparison of Private and Public Sector Developments

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ABSTRACT The paper compares private and public sector developments relating to radon mitigation in the U.S. In response to elevated radon levels in many U.S. houses, the Federal and State governments and the private sector have undertaken many varied mitigation and public information efforts resulting in a range of radon reduction installations in the U.S. Government-sponsored research and development of radon mitigation techniques in single-family detached houses is compared with radon mitigation approaches undertaken by the private sector. An attempt is also made to compare premitigation diagnostics, the application of mitigation techniques to various substructure types, the performance of mitigation installations, and the cost of the installations. The information collected indicates that subslab ventilation is the most common technique in both public and private sector radon mitigation; however, air-to-air heat exchangers and sealing are employed more frequently in the private sector than in government-sponsored mitigation.

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RADON MITIGATION CHOICES IN THE UNITED STATES – A COMPARISON OF PRIVATE AND PUBLIC SECTOR DEVELOPMENTS

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Abstract — The paper compares private and public sector developments relating to radon mitigation in the US. In response to elevated levels of radon in many houses throughout the U.S., the Federal and State governments and the private sector have undertaken many varied mitigation and public information efforts resulting in a range of radon reduction installations in the U.S. Government sponsored research and development of radon mitigation techniques in single-family detached houses is compared with radon mitigation approaches undertaken by the private sector. An attempt is also made to compare premitigation diagnostics, the performance of mitigation installations, and the cost of the installations. The information collected indicates that sub-slab ventilation is the most common technique in both public and private sector radon mitigation; however, air-to-air heat exchangers and sealing are employed more frequently in the private sector than in government sponsored mitigation.

INTRODUCTION

In response to elevated levels of radon in many houses throughout the U.S., the Federal and State governments and the private sector have undertaken many varied mitigation and public information efforts resulting in a range of radon reduction installations. Government sponsored research and demonstration of radon mitigation techniques in single family detached houses is compared with radon mitigation approaches undertaken by the private sector. An attempt is also made to compare premitigation diagnostics, the performance of mitigation installations, and the cost of the installations. Due to varying methods and extents of data collection, it is often difficult to make a direct comparison between mitigation installations obtained from different sources. In such cases, the information available is presented, and a qualitative comparison is made.

GOVERNMENT SPONSORED RADON MITIGATION

Government approaches to radon mitigation discussed in this paper focus on the U.S. Environmental Protection Agency's (EPA) radon reduction field projects, EPA's House Evaluation Program (HEP), and selected mitigation information from State radon programmes.

The objective of EPA's Radon Mitigation Research Program is to develop and demonstrate cost-effective radon reduction methods applicable to all house substructure types. To accomplish this, EPA's Office of Research and Development (ORD) is sponsoring research and demonstration of selected radon mitigation techniques in houses in several field projects located in Pennsylvania, New Jersey, New York, Maryland, Florida, Tennessee, Alabama, and Ohio. Two-thirds of the houses mitigated thus far are block basement or combination basement and slab-on-grade substructures. Crawl space, slab-on-grade, and combination substructures are receiving emphasis in the field projects recently underway. Mitigation information gained from EPA's research has been conveyed to the public through brochures[1,2], a technical manual[3], workshops, conferences, and interviews with the media.

EPA's Office of Radiation Programs (ORP) has established the HEP to assist the States in evaluating mitigation approaches for reducing elevated indoor radon levels. Eighty HEP houses have been evaluated in Pennsylvania and are currently being mitigated through Pennsylvania's Department of Environmental Resources (DER) Radon Gas Demonstration Project as discussed below. HEP projects have also begun in New York, New Jersey, and several other states.

In response to the identification of localised radon 'hot spots' many states have also developed radon programmes. For example, the Department of Environmental Protection (DEP) and the Department of Health (DOH) in New Jersey began to develop the New Jersey Radon Program in 1985. The programme includes confirmatory monitoring for houses with initial screening levels of 148 $Bq.m^{-3}$ or greater (personal communication with Jou Hwang of DEP and Reference 4). New Jersey has

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also worked with EPA in the remediation of houses in Clinton, New Jersey, and the State is jointly supporting a detailed research project in the piedmont region of New Jersey with EPA and the U.S. Department of Energy.

Pennsylvania's DER has also developed a radon programme including free follow-up testing of houses with initial screening levels greater than 740 $Bq.m^{-3}$, free post-mitigation testing for homeowners who have installed some substantial remediation work (survey data have been compiled on over 200 houses), and the initiation of a number of pilot study programmes with free screening within the geographic area of the study[5]. The 80 houses in Pennsylvania evaluated under EPA's HEP, together with an additional 25 houses, are currently being mitigated as part of DER's Radon Gas Demonstration Project. To date, 43 of these houses have been completely remediated (personal communication with Tim Hartman of DER).

RADON MITIGATION IN THE PRIVATE SECTOR

Information on mitigation practices in the private sector was collected from three sources, an ORP pilot survey of radon mitigation firms, Pennsylvania's DER post-mitigation survey, and a 457-house remediation survey by the New Jersey DEP.

ORP recently completed a pilot survey by contacting selected contractors who have performed extensive mitigation work in the private sector. The survey respondents have installed mitigation systems in over 1400 houses in Connecticut, Delaware, the District of Columbia, Maryland, New Jersey, New York, Pennsylvania, and Virginia. Most of the houses mitigated had basements with adjoining slabs. Responses to the survey tend to be more qualitative than quantitative since most firms usually do not keep detailed records of their mitigation installations[6].

Pennsylvania's DER has compiled data on more than 200 mitigation installations in the private sector of Pennsylvania as part of the State's follow-up testing for homeowners who have completed some substantial remediation[5]. The information available is limited to mitigation technique, performance, and cost.

The New Jersey DEP has also collected data on radon reduction installations in the private sector. Data on mitigation techniques installed and pre- and post-mitigation ranges of radon concentration are compiled for 457 houses in New Jersey (personal communication with Jou Hwang of DEP).

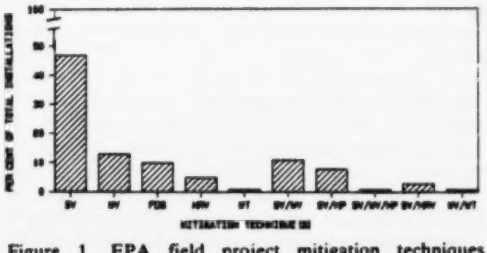

Figure 1. EPA field project mitigation techniques installed.

PREMITIGATION DIAGNOSTICS

Some degree of diagnostic testing is often performed prior to selection and design of a mitigation installation. Although the extent of premitigation diagnostics varies between EPA's field projects, certain diagnostics are applicable to each project: detailed visual inspection of house-specific characteristics and construction, identification of potential radon entry points, measurement of subslab/wall air flow communication, measurement of depressurisation due to appliance usage, analysis of various soil characteristics, determination of building material and/or water as a radon source, and the measurement of integrated radon levels prior to mitigation. Premitigation diagnostics such as measurement of air infiltration rates using a blower door or tracer gases are often also included to gain additional information about the house.

Specific premitigation diagnostics vary between the 24 contractors actively participating in Pennsylvania's Radon Gas Demonstration Project. In general, diagnostics include a detailed visual inspection of the house and measurements of sub-slab communication if sub-slab ventilation is being considered as a mitigation option (personal communication with Tim Hartman of DER).

Diagnostics generally performed by private firms responding to ORP's pilot survey include verification of radon concentration, details of house construction, HAC (heating and air conditioning) information, and determination of whether water is a potential radon source. if sub-slab ventilation is being considered as a mitigation option, some of the firms test sub-slab communication by drilling holes and using a tracer gas while others rely on experience with similar houses. Some firms in the pilot survey note the presence of appliances that could cause house depressurisation or affect the circulation of indoor air, and sometimes information on house age and occupant activity is collected[6].

MITIGATION TECHNIQUES

Mitigation installations in EPA's development and demonstration projects are usually phased, and often involve testing of more than one technique or combination of techniques in a given house. Both final and intermediate installations are discussed below, although it should be noted that intermediate phases are often installed for research purposes, and their performances tend to be lower than for the final mitigation installations. Much field work is currently in progress, and the information presented in this paper represents EPA mitigation installations to date.

Figure 1 shows the relative percentages for choice of mitigation technique for the 64 final installations for the field projects located in Pennsylvania and New Jersey. The following list gives the abbreviations used for the various techniques in Figure 1 and subsequent illustrations.

Mitigation symbol	Technique
SV	Sub-slab ventilation
WV	Block wall or baseboard ventilation
FDS	Foundation drain suction
HRV	Heat recovery ventilation or air-to-air heat exchanger
WT	Water treatment
HP	House pressurisation
FWJS	Floor/wall joint suction
CSV	Crawl space ventilation
SEAL	Sealing or plugging of cracks, joints or holes
AHV	Active house ventilation
PHV	Passive house ventilation
SPFD	Seal sump and/or French drain
PT	Paint block walls and/or floors
COMB	Undefined combination
MISC	Other

Mitigation involving active soil gas ventilation is clearly the first choice, comprising over 90% of these techniques and combinations of techniques. Nearly 75% of the installations are sub-slab ventilation either alone or in combination with another technique. The most prevalent combination of mitigation techniques is sub-slab and wall ventilation. Although sealing is often involved in the soil ventilation installations, sealing as a technique by itself was not left as a final installation. Ventilation using a heat recovery ventilator (HRV) and treatment of radon in water have been installed as final techniques in a few of EPA's field projects (about 10%).

The 246 installations to date, including both the final and the intermediate installations in EPA's field projects, are similar to the final installations discussed above. Again, most of the installations involve active soil gas ventilation with sub-slab ventilation installed most frequently. Mitigation techniques also studied in the intermediate phases of installation include increased house ventilation using a HRV, treatment of radon in water, house pressurisation, and sealing.

The emphasis of EPA's field projects discussed above has been on techniques involving active soil gas ventilation, specifically sub-slab ventilation. This emphasis was due largely to initial radon levels as high as 55,500 $Bq.m^{-3}$ encountered in these early projects and the familiarity with and confidence in soil ventilation techniques in reducing these high radon levels. Current EPA field projects are focussing on the remediation of houses with lower radon levels (370 to 1850 $Bq.m^{-3}$) that, nation-wide, present a greater public health risk. More diverse and lower cost mitigation techniques, such as control of house pressure, sealing, and passive soil gas ventilation, are also being actively investigated.

To date, 43 houses, including ORP's HEP houses, have been mitigated in Pennsylvania's Radon Gas Demonstration Project. Since mitigation is still in progress, specific installation information is not available at this time. In general, sub-slab ventilation has been the preferred mitigation technique. Some installations have included several phases of mitigation, and techniques such as sealing, isolation, and pressurisation have also been installed (personal communication with Tim Hartman of DER).

Firms responding to the ORP pilot survey usually install phased mitigation techniques beginning with the simplest and least expensive. If the initial radon concentration is less than 740 $Bq.m^{-3}$, the first phase often involves the caulking and sealing of all joints, cracks, and penetrations in contact with the soil, covering and venting sumps, and the sealing of crawl spaces with plastic. If sealing is not successful or levels are too high for sealing alone to be an option, a sub-slab ventilation system with one to three points is usually installed, depending on sub-slab communication, the contractor, and homeowner preference. Other mitigation techniques installed by private firms include house ventilation with a HRV, house pressurisation, and treatment of radon in water. Initial radon concentrations remediated by contractors are generally in the range of 1500 to 3700 $Bq.m^{-3}$; however, one contractor reported that half of the houses he mitigated had levels greater than 3700 $Bq.m^{-3}$[6]. Many firms responding to the pilot survey indicated that, due to their high level of confidence, sub-slab ventilation systems are sometimes installed to mitigate relatively low radon

concentrations (less than 370 Bq.m^{-3}) due to a pending real estate sale[6].

Private sector mitigation choices compiled from DER's post-mitigation survey are shown in Figure 2. Mitigation techniques involving active soil ventilation are most prevalent, comprising 43% of the installations. Sub-slab ventilation is the most common technique in the post-mitigation survey, although sealing and/or passive house ventilation are also popular choices. Many of the contractors also chose to install an HRV.

The radon reduction measures installed in 457 New Jersey houses are shown in Figure 3. Sub-slab ventilation is the most common technique, comprising 30% of the installations. Sealing of the sump hole and/or French drains, installation of HRVs, and sealing of cracks are also prevalent remediation measures in the New Jersey private sector (personal communication with Jou Hwang of DEP).

PERFORMANCE OF MITIGATION INSTALLATIONS

The performance ranges of final mitigation installations in EPA's field projects are shown in Figure 4. Performances of techniques involving soil gas ventilation were most successful, ranging from 65% to nearly 100% radon reduction, corresponding to radon concentrations of 37 to 777 Bq.m^{-3}.

For the 43 houses remediated in Pennsylvania's Radon Gas Demonstration Project, performances ranged from 90% to 100% radon reduction, corresponding to post-mitigation radon concentrations of 22 to 104 Bq.m^{-3} for all types of mitigation techniques installed.

Most of the mitigation firms contacted for the pilot survey do not make post-mitigation radon measurements due to potential conflict of interest; consequently, it is often difficult for the firms to keep detailed records of mitigation performance. In general, the firms reported that they achieve radon

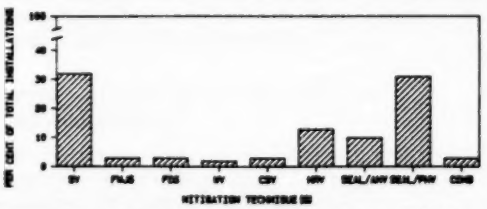

Figure 2. Pennsylvania private sector mitigation techniques installed.

Figure 3. New Jersey private sector mitigation techniques installed.

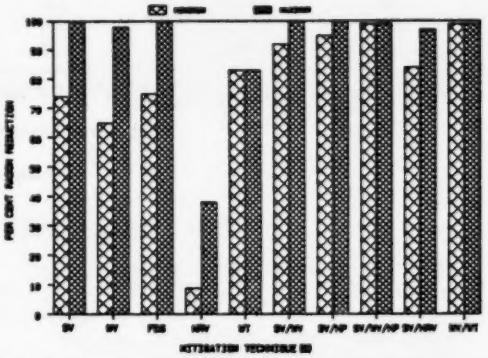

Figure 4. EPA field project mitigation performance range.

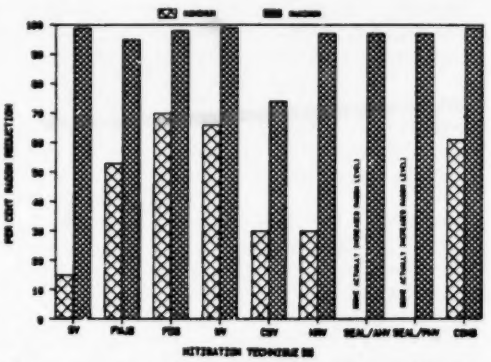

Figure 5. Pennsylvania private sector mitigation performance range.

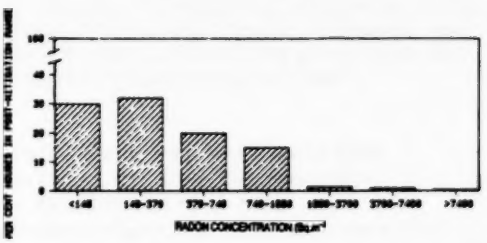

Figure 6. New Jersey private sector mitigation performance range.

Table 1. Estimated costs of radon mitigation.

Mitigation technique	Initial expenses (1987 U.S. dollars)			
	Government		Private Sector Surveys	
	EPA[a]	DER[b]	ORP[c]	DER[d]
Overall average	NA	4329	500-1500	1000
Active soil ventilation	1050-5200	NA	400-2500	NA
HRV	2700	NA	1200-3000	NA
Simple house ventilation	400-800	NA	NA	NA
Sealing	550-3700	NA	50-1500	NA
Sealing crawl space	NA	NA	100-500	NA

[a] ORP's estimated costs for radon reduction to an annual average of 148 $Bq.m^{-3}$ in houses with basement, crawl space, and slab-on-grade substructures.
[b] Average cost per installation (personal communication with Tim Hartman of DER).
[c] Estimated mitigation costs from pilot survey respondents[6].
[d] Approximate average mitigation cost for DER post-mitigation survey[5].

levels below EPA's recommended level (148 $Bq.m^{-3}$) 90% of the time with sub-slab ventilation[6].

Performance data for DER's post-mitigation survey of private sector installations are shown in Figure 5. Performances for active soil ventilation ranged from 15% to 99% reduction; the next most common technique, sealing and/or passive house ventilation, exhibited a performance range from an increase in radon to 97% reduction. Since various means of pre- and post-mitigation testing were often used, do not place too much emphasis on the minimum and maximum per cent reductions.

Detailed data relating performance to specific technique are not available for the New Jersey DEP study; however, the per cent of houses in various post-mitigation radon concentration ranges are shown in Figure 6. Of these houses, 70% exhibited post-mitigation radon concentrations exceeding 148 $Bq.m^{-3}$, and 38% exceeded 370 $Bq.m^{-3}$.

ESTIMATED COSTS OF MITIGATION INSTALLATIONS

The estimated costs of various radon mitigation techniques are shown in Table 1. The government estimates for costs of mitigation tend to cover a wider range and are somewhat higher than private sector costs. The higher costs are due in large part to the research data collected and additional overhead costs incurred in government sponsored mitigation.

CONCLUSIONS

A comparison of government and private sector radon mitigation in the U.S. yields the following conclusions:

1. Available information on premitigation diagnostics indicates that both the public and private sectors collect detailed house characteristic information, and usually measure sub-slab communication; however, Federal government sponsored mitigation tends to collect more data for research and development purposes.
2. Sub-slab ventilation is the most common mitigation technique in both the public and private sectors. HRVs and sealing are employed more frequently in the private sector than in government sponsored mitigation.
3. Maximum performances of mitigation techniques are similar in both the public and private sectors; however, minimum per cent reductions are difficult to compare due to varying initial radon levels. Performance data on private sector mitigation, compiled by the State of New Jersey, indicate that a large percentage of mitigation installations do not reduce indoor concentrations to below 148 $Bq.m^{-3}$.
4. Although it is difficult to compare cost data without knowing more detailed information, cost estimates tend to be lower for the private sector than for government sponsored installations.

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